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Factors affecting growth rate of dairy calves

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FACTORS AFFECTING GROWTH RATE OF DAIRY CALVES

by

Truman Glen Martin

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
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Major Subject: Dairy Husbandry

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Signature was redacted for privacy.

In Charge of Major Work

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Dean of Graduate College

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I. INTRODUCTION

According to Agricultural Statistics (69), there are more than seven million dairy calves raised as herd replacements and vealers each year. The importance of calf raising has been recognized by research workers and considerable work has been directed toward determining what dietary and managerial practices should be followed. In order to compare various dietary and managerial regimes, some measure of adequacy is necessary.

Breeders of dairy cattle consider rapid growth to be an index of constitution, vigor, and general desirability. Dairy cattle nutritionists consider growth rate to be an indication of ration adequacy. No really good definition of growth exists but growth can occur by cell multiplication, cell enlargement, or deposition of material between the cells. The first of the above is probably most important in the young animal. Most commonly, growth is thought of as simply an increase in size which may be measured by weight increase or by increase of some particular one or set of body measurements.

Following this, it is reasonable to ask what factors affect growth rate. Practical dairy husbandmen have long recognized that the sexes and the breeds differ in both birth weight and growth response. Calves within a breed

and/or sex also differ in birth weight and growth rate. It could be postulated that birth weight and growth rate are related and that this relationship should be considered in the design of calf nutrition experiments. Due to the climatic differences from one season to another, growth rate could be affected by seasonal variation. Inheritance of ability to grow could be an important factor affecting growth rate.

Next, one would like to ascertain how growth rate affects such characteristics as age at calving, mature size, and production.

Research workers, in order to better plan and interpret their work, would like to know:

(1) How to measure growth,

(2) The magnitude of breed, sex, and season of birth effects and whether or not they should be considered in designing calf nutrition experiments,

(3) The relationship of birth weight to growth rate,

(4) The heritability of growth rate, and

(5) How growth rate in early stages of life affects age at first calving, production, and mature size.

This study was designed originally to try to answer as many of the above questions as possible. Data limitations ruled out studies of heritability of growth rate and relationship of growth rate to mature size. Only body weight

data were considered; therefore, growth in linear body measurements could not be compared with growth in body weight as measures of the adequacy of rations.

This study was designed to evaluate the effects of breed, sex, season of birth, ration, and birth weight on growth in body weight, to obtain some indication of the value of relative growth rate as a measure of growth, and to obtain an estimate of the relationship of growth rate to age at calving and milk production.

II. REVIEW OF LITERATURE

An adequate description of growth has been the quest of many research workers in the past. The subject of growth is discussed in detail by Brody (15); therefore, only the more pertinent ideas will be presented here. Robertson (59) described the growth process as being composed of several phases each being sigmoid (S shaped) in nature and the junction between two phases being a critical point in the animal's life. Brody (11) described growth as being composed of a self-accelerating phase and a self-inhibiting phase with the two joining in the most rapid period of growth which is at the point of inflection of the growth curve and near puberty in the physiological development of the animal. The self-accelerating phase was shown (12) to be composed of several discontinuous periods with the relative rate of growth being constant in each period. Rate of growth in the self-inhibiting phase was defined (13) as being a constant proportional to the distance from the mature size of the animal.

Description of growth is further complicated by the fact that there is both skeletal growth and fleshy growth. What affects one may not affect the other. Touchberry (63) divided body size into a general factor, group factors affecting fleshy or skeletal size independent of each other,

and specific factors affecting each body measurement independent of the other measurements. Body weight, paunch girth and heart girth were the measurements associated with fleshiness while body length, wither height, chest depth and heart girth made up the skeletal group. Blackmore (9) confirmed the logic of these groupings and also found that the general factor tended to mask the group and specific factors at early ages.

Brody (14) described growth in body weight as tridimensional in nature and proceeding as a geometric progression while the linear body measures are confined to one and, at the most, two dimensions and, consequently, result in a growth rate more nearly corresponding to an arithmetic progression. Growth curves of linear measures were plotted by Brody and Ragsdale (18) showing that early in life there is a rapid increase in all measures. The above was confirmed by Guilbert and Gregory (33) who plotted growth curves of linear measures of beef cattle. The age at which mature size is reached for the various body measurements seems to vary considerably as shown by Brody (14), and Hansson and Bonnier (34).

Variation in age of maturation among the various body measures results in a change of conformation during the maturation process. The above was demonstrated by Brody and Ragsdale (17). Brody (14) described skeletal growth

as being composed of a period of constant rate of increase and a period of decreasing rate of increase. In summation, the early growth of all body measures is rapid, and growth in one body measurement is correlated with growth in all other measurements indicating that the general growth factor is exerting itself. Eckles (21) and Touchberry (63) demonstrated that environment influenced weight gain more than increase in wither height. This would seem to indicate that dietary insufficiency would result in a more prominent role of the group and specific growth factors. Thus, weight change emerges as the most easily detected measure of dietary adequacy for growth.

Ration has been demonstrated to affect body weight and/or linear measurements by Eckles (21), Eckles and Swett (25), Flipse and Almquist (29), Reid (58), Hansson et al. (35) and others too numerous to cite. The above workers carried their studies to about two years of age and found that animals underfed in early life: (1) were as large at maturity as, (2) grow slower but longer than, (3) reached sexual maturity later than, (4) lived longer than, and (5) produced as much or more milk in the first lactation than liberally fed animals.

Sex of the calf and season of birth was shown to affect growth of beef calves by Rollins and Guilbert (60). Rathore (57) demonstrated breed and sex effects on growth.

Baker et al. (6), Nelson and Lush (50), and Blackmore (9) demonstrated that an increased degree of inbreeding caused a decrease in body size. This being true, growth rate probably would decrease also as inbreeding increased. Baird et al. (5) found a significantly higher concentration of growth hormone in the anterior pituitary of pigs from a line selected for rapid growth rate than in the anterior pituitary of pigs from a similar line selected for slow growth rate. Hazel et al. (37) found growth rate to be heritable in swine. Touchberry (63), Blackmore (9) and Tyler et al. (67) demonstrated body size of dairy cattle to be 15 to 80 per cent heritable. Blackmore and Tyler reported a tendency for heritability of body size to increase with age. Espe et al. (26) found early weights to be subject to greater variability than later weights as measured by the coefficient of variation. From the above observations it would appear that growth rate is genetically affected but that growth response in the early period of life is highly subject to environmental fluctuations.

The influence of birth weight on gain has been argued both pro and con. In dairy cattle, Eckles and Swett (25) found birth weight not to be associated with growth rate while Willard (71) found an association between birth weight and gain. Neither computed correlations. Birth weight and gain would be more subject to a common maternal effect in

beef cattle and swine than in dairy cattle. Correlation of birth weight and gain would tend to follow the magnitude of maternal effects on gain. Forshaw et al. (30) observed a correlation of .46 between birth weight and weaning weight of Duroc pigs. Dawson et al. (20) found the following correlations in beef cattle: birth weight with days to weaning (500 pounds), -.28; birth weight with days to slaughter (900 pounds), -.62; and birth weight with days from weaning to slaughter, -.04. Arizona workers (2) found a correlation of .597 ± .031 between birth weight and daily gain to weaning.

Rathore (57) observed that the pattern of differences in size between breeds at birth was more nearly the pattern of breed differences in size at older ages than at younger ages. The above would imply that differences in size at six months or one year of age are more closely associated with birth weight than differences in size at one month or two months of age. Again, it appears that early growth rate is easily affected by environmental fluctuations. It also seems that the association between birth weight and growth rate has not been clearly defined.

Factors influencing birth weight have been studied rather extensively. Eckles (22, 23) and Fitch et al. (28) reported breed, sex of calf and age of dam to affect birth weight while the sire, nutrition of the dam, and length of

gestation failed to affect birth weight. Tyler et al. (66), studying three unrelated Holstein herds, found herds, sex of calf, and calving sequence to affect birth weight while season and year of birth had no effect on birth weight. Rathore (56) found sex of calf, calving sequence, length of gestation, length of preceding dry period, sire, and year of birth to affect birth weight, while season of birth did not affect birth weight. It follows that, if birth weight affects rate of growth and if birth weight is affected by all the above factors, all of the above factors influence growth rate of the calf. This points to a vast complex of factors affecting the growth rate of a given calf, some of which are environmental and some of which are hereditary. Fortunately, the literature previously cited indicates that many of these are of little consequence and can be ignored.

"Normal" growth curves for body weight and certain of the body measurements have been tabulated. Average values for weight, wither height, chest depth and width at hooks were tabulated for Holstein, Guernsey, Jersey, and Ayrshire females by Espe et al. (26). Graphs of growth in seven body measurements were prepared by Ashton (3) for the Lombardy, Brown Swiss, Brittany, Dairy Shorthorn, Ayrshire and Beef Shorthorn breeds. Missouri workers have presented average values for Ayrshires, Guernseys, Holsteins, Milking Shorthorns, and Jerseys in several reports (53, 24, 65, 55,

16, 54). One of the above (53) has been accepted rather widely as a growth standard. Morrison (47) summarized data from several experiment stations to develop growth curves for Ayrshire, Guernsey, Holstein, and Jersey heifers. Campbell and Flux (19) derived a standard growth curve for Jerseys and Holsteins in New Zealand. The above average curves were similar for like breeds and sexes. Ragsdale and Regan (55) graphically represented the great variability of animals taken from several environments and averaged to obtain growth standards. There appear to be sufficient average curves in the literature to serve as standards for comparison of the adequacy of environmental conditions for growth. However, the great variability shown by Ragsdale and Regan (55) plus the fact that they observed differences among herds would tend to indicate that a standard curve should be used with some discretion and that the selection of the appropriate curve deserves careful consideration.

Plum et al. (52) correlated increase in size between 10 and 12 months of age with milk production and found both wither height and heart girth gain to be positively correlated with milk production. There was no genetic relationship between heart girth gain and milk production, but wither height gain and milk production had a genetic correlation of .69. Straus (62) found an intra-sire correlation of .17 between birth weight and milk production while

Blackmore (9) found an intra-sire correlation of .068 based on birth weights corrected for age of dam.

Bailey and Broster (4), Gjelstad (32), Touchberry (63), and Blackmore (9) all found a low degree of genetic relationship between body weight and milk production. Bailey and Broster (4) and Gjelstad (32) found phenotypic correlations of .24 and .01, respectively, between body weight and milk production. Turner (64) considered milk production and body weight to be related and devised a factor for correcting production records for variation in body size.

It seems that neither growth in body weight nor mature body weight is closely associated with milk production. There is no strong evidence that birth weight is closely associated with milk production. Growth and mature size in certain body measurements such as wither height have been shown to be correlated with milk production by Plum et al. (52) and Blackmore (9).

III. SOURCE AND CLASSIFICATION OF DATA

Data used in this study were obtained from nutrition experiments involving dairy calves at Iowa State College from 1945 to 1954. The type of experiments included vary widely but the general management practices remained relatively constant. Calves were allowed to remain with their dams for 3 days following birth, after which they were removed to another barn and placed in individual pens. Milk or milk replacement was fed from nipple pails. Hay, when fed, was placed in a hay rack and periodically replaced with fresh hay. Concentrate mixture, when fed, was placed in a grain box and allowed to remain until eaten or until it became contaminated, at which time it was replaced with fresh concentrate mixture. The general rate of feeding concentrate mixture was ad lib to a maximum of 2 pounds twice daily. Specific rates of milk feeding and deviations from the above general management plan can be found by referring to the proper references listed in Table 1.

Each calf was weighed at 4 days of age and weekly thereafter to the termination of the particular experiment to which that calf was assigned. All calves were on experiment for at least 8 weeks with some being on experiment 12 weeks and some longer than 12 weeks. For this study, weights were recorded at the following ages: 4, 11, 18, 25, 32,

Table 1. Experiments included in study of growth

Experiment code no.	Experiment title	Reference
1	Milk replacements	Young (75)
2	Absorption of vitamin A	Blake (10)
3	Aureomycin feeding	Murley (49)
4	Reconstituted milk products	Wing (72)
5	Filled milks	Jacobson (39)
6	Filled milks	Murley (48)
7	Toxic soybean oil meal	Jacobson (41)
8	Milk replacement	Jacobson (43)
9	Absorption of vitamin A	Yang (73)
11	Filled milks	Barker (7)
12	Calf starters	Jacobson (40)
13	Dietary fat	Bate (8)
14	Comparative antibiotic	Voelker (70)
15	Second generation aureomycin	Jacobson (42)
16	Comparative antibiotic	Owen (51)
17	Milk replacement	Jacobson (43)

39, 46, 53, 60, 67, 74, 81, 88, 116, and 144 days. These data were supplemented by 6 and 12 month weights when available.

A total of 659 calves were included in this study. Each animal was classified according to breed (five major dairy breeds), sex, season of birth (Winter, December to February; Spring, March to May; Summer, June to August; and Fall, September to November), and ration. Ration classification presented a problem inasmuch as there were 16 separate experiments, each having two or more individual rations. In order to have a reasonable number of animals in most ration classes and still remove most of the variation attributable to rations, the classification system shown in Table 2 was devised. This classification was based on the ration fed to 8 weeks of age.

This classification would have been reasonably sufficient for the Holstein breed, though some of the classes were rather small. For the other breeds, where numbers were smaller, this classification would have had entirely too many cells represented by only one or two animals; therefore, the detailed classification in Table 2 was rejected in favor of a broader classification.

Several workers (43, 49, 75) found little difference between milk replacements and whole milk. Owen (51) and Voelker (70) failed to demonstrate a growth response to

Table 2. Number of Holstein calves in each ration classification

Type of milk	Amount of milk			
	1. Liberal milk[a] + hay and concentrate	2. Intermediate milk[b] + hay and concentrate	3. Limited milk[c] + hay and concentrate	4. Milk only
1. Whole milk	24	50	14	28
2. Milk replacement[d]	9	33	58	52
3. Milk replacement + other antibiotics			26	
4. Whole milk + aureomycin or terramycin	4		10	
5. Milk replacement + aureomycin or terramycin	4		41	8
6. Milk replacement containing unhydrogenated vegetable oil	3	12		13

[a]Over 450 pounds milk per 100 pounds birth weight.
[b]300 to 450 pounds milk per 100 pounds birth weight.
[c]Under 300 pounds milk per 100 pounds birth weight.
[d]Skim milk, skim milk plus vegetable fats, or any other replacement for whole milk.

antibiotics other than aureomycin or terramycin. Based on the above findings, the first three types of milk listed in Table 2 were combined and the fourth and fifth types of milk were combined. Filled milks containing unhydrogenated vegetable oils were shown (7, 8, 39, 48) to inhibit growth, so that classification was retained. Aureomycin or terramycin rations were separated from the others because Murley (49), Voelker (70), and Owen (51) have shown that those antibiotics stimulate growth in young calves.

Since there was a relatively small number of calves in the "liberal milk" classification, the first two vertical columns were combined and designated as "liberal milk". Due to limited numbers, the calves fed antibiotics were grouped disregarding level of milk feeding. Calves receiving rations containing unhydrogenated vegetable oils were grouped similarly. Thus, the classification resolved itself to five rations: (1) antibiotics added, 67 calves; (2) liberal milk plus hay and grain, 116 calves; (3) limited milk plus hay and grain, 98 calves; (4) milk only, 80 calves; and (5) unhydrogenated vegetable oil added, 28 calves. The number of calves actually on each ration is increased over the above figures when the four breeds other than Holsteins are included. The combination of rations in Table 2 forming each ration group listed above is blocked off by India ink lines.

It can be argued that the animals should have been grouped according to experiment also, but Tables 3 and 4 reveal extremely non-orthogonal relationships which would tend to make the fit of constants to the data unrealistic if experiment effects were included in the model. Experiment effects were highly confounded with ration effects. It was desired to have some rather realistic estimate of ration effects; therefore, both experiment and year classifications were eliminated in this study.

Table 3. Number of calves[a] having 8-week gain values classified by ration and experiment

Experiment	Ration				
	1	2	3	4	5
1			48		
2		24			
3	33	21		5	
4				72	
5				20	9
6				10	9
7		16			
8			9		
9		10			
11		20		5	5
12		59			
13		40		5	26
14	18	17	24		
15	17		13		
16	6		24		
17	28				

[a]All breeds.

Table 4. Number of Holstein calves having 1-year gain values classified by ration and experiment

	Ration				
Experiment	1	2	3	4	5
1			23		
2		9			
3	7	3		1	
4				22	
5				13	4
6				6	5
7		4			
8			6		
9		7			
11		8			1
12		22			
13		15			9
14	12	16	16		
15			1		
16	1		3		

IV. ANALYSIS OF DATA

A. Method of Least Squares for Non-orthogonal Data

Detailed descriptions of the least squares technique used in this study have been made by Hazel (36), Henderson (38), Yates (74), Kempthorne (44), and Koch (45). Since the technique has been described so often, there is no need of describing it here beyond a brief outline of the application of the method to the particular data analyzed in this study.

The model assumed for this study is:

$$Y_{ijk\ell m} = \mu + T_i + B_j + S_k + R_\ell + e_{ijk\ell m}$$

where: $Y_{ijk\ell m}$ is gain of the m^{th} calf ($m = 1$ to $n_{ijk\ell}$ and $n_{ijk\ell}$ = number of calves in the $ijk\ell^{th}$ cell of the classification) in the $ijk\ell^{th}$ cell of the classification; μ is a general effect common to all calves; T_i is an effect common to all calves of the i^{th} sex, $i = 1$ to 2; B_j is an effect common to all calves of the j^{th} breed, $j = 1$ to 5; S_k is an effect common to all calves of the k^{th} season, $k = 1$ to 4; R_ℓ is an effect common to all calves of the ℓ^{th} ration, $\ell = 1$ to 5; and $e_{ijk\ell m}$ is an effect peculiar to the m^{th} calf of the $ijk\ell^{th}$ cell of the classification.

By rearranging the model, expressing the sum of $e_{ijk\ell m}$ in terms of the parameters, differentiating $\sum_{ijk\ell m} e^2_{ijk\ell m}$ with

regard to each of the parameters, and setting half of each partial differential equal to zero, the normal equations are derived. Setting the condition, $\sum_i T_i = \sum_j B_j = \sum_k S_k = \sum_\ell R_\ell = 0$, on the normal equations and solving the normal equations, constants are derived which can be used to obtain unbiased estimates of differences between the T_i, the B_j, the S_k, and the R_ℓ. The constant, $\hat{w}$, derived from these equations, is an estimate of $w + \bar{T} + \bar{B} + \bar{S} + \bar{R}$ and $\hat{T}_i$, $\hat{B}_j$, $\hat{S}_k$, and $\hat{R}_\ell$ are estimates of $T_i - \bar{T}$, $B_j - \bar{B}$, $S_k - \bar{S}$, and $R_\ell - \bar{R}$, respectively.

A rather simple test for the presence of pooled interactions is present inasmuch as a straightforward analysis of variance testing differences among cell means is unbiased even though the number of observations varies from cell to cell. The analysis of variance is symbolized in Table 5. The sum of squares reduction due to fitting constants w,

Table 5. Among cell analysis of variance

Source of variance	d.f.	S.S.	M.S.	F
Mean	1	A		
Among cells	N_c	C	$\frac{C}{N_c}$	$\frac{CN_e}{EN_c}$
Within cells	N_e	E	$\frac{E}{N_e}$	

the T_i, the B_j, the S_k, and the R_ℓ is the sum of the products of the constants and the right hand sides of their respective equations. Reduction sum of squares is symbolized by $R(\mu, T, B, S, R) = Q$. An estimate of interactions is obtained by: $A + C - Q$. Degrees of freedom for $R(\mu, T, B, S, R)$, symbolized by N_r, are one for the mean, one for sex, four for breed, three for season, and four for ration, totalling 13. A test for interactions is symbolized in Table 6.

Table 6. Analysis of variance (test of pooled interactions)

Source of variance	d.f.	S.S.	M.S.	F
$R(\mu, T, B, S, R)$	N_r	Q		
Interactions	$N_c - N_r + 1$	$A+C-Q$	$\frac{A+C-Q}{N_c-N_r+1}$	$\frac{N_e(A+C-Q)}{(N_c-N_r+1)E}$
Error	N_e	E	$\frac{E}{N_e}$	

The reduction sum of squares due to fitting any one classification after the other three can be obtained in one of two ways: (1) by difference, for example, $R(\mu, T, B, S, R) - R(\mu, T, B, S)$ = sum of squares due to fitting ration constants after fitting μ, sex constants, breed constants, and season constants, (2) the sum of the products of the constants by the right hand sides of the reduced normal

equations. The method of reducing the normal equations to expressions of one classification is fully described by Kempthorne (44). Inversion of the symmetric matrix resulting from reduction of the normal equations yields a variance-covariance matrix in that classification. Since there are five rations, there would be five reduced equations in the five R_ℓ which could be symbolized by the following matrix notation:

$$\begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} \\ r_{31} & r_{32} & r_{33} & r_{34} & r_{35} \\ r_{41} & r_{42} & r_{43} & r_{44} & r_{45} \\ r_{51} & r_{52} & r_{53} & r_{54} & r_{55} \end{bmatrix} \begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \\ R_5 \end{bmatrix} = \begin{bmatrix} P_1^a \\ P_2 \\ P_3 \\ P_4 \\ P_5 \end{bmatrix}$$

If the five by five r matrix (λ) is augmented by a row of ones and a column of ones except the sixth position which is given a value of zero, λ becomes:

$$\lambda' = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} & 1 \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} & 1 \\ r_{31} & r_{32} & r_{33} & r_{34} & r_{35} & 1 \\ r_{41} & r_{42} & r_{43} & r_{44} & r_{45} & 1 \\ r_{51} & r_{52} & r_{53} & r_{54} & r_{55} & 1 \\ 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix}$$

and the inverse is:

---

[a] P_ℓ = right hand side of the ℓ^{th} reduced equation.

$$\lambda'^{-1} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & 1/5 \\ c_{21} & c_{22} & c_{23} & c_{24} & c_{25} & 1/5 \\ c_{31} & c_{32} & c_{33} & c_{34} & c_{35} & 1/5 \\ c_{41} & c_{42} & c_{43} & c_{44} & c_{45} & 1/5 \\ c_{51} & c_{52} & c_{53} & c_{54} & c_{55} & 1/5 \\ 1/5 & 1/5 & 1/5 & 1/5 & 1/5 & 0 \end{bmatrix}$$

Variance $R_\ell = c_{\ell\ell}\sigma^2$, covariance $R_\ell R_{\ell'} = c_{\ell\ell'}\sigma^2$, and variance $R_\ell - R_{\ell'} = (c_{\ell\ell} + c_{\ell'\ell'} - 2c_{\ell\ell'})\sigma^2$ where σ^2 is estimated by the error or within cell mean square of the analysis of variance symbolized in Tables 5 and 6.

In the analysis of covariance, two sets of constants are derived, one for the independent variable and one for the dependent variable. Constants are fitted for both variables and the sums of squares are derived as above while the sums of cross products are obtained by summing the products of the constants of one variable and the right hand sides of the other variable.

B. Effects of Breed, Sex, Season of Birth, and Ration on Growth

1. Growth from 4 to 60 days of age

Of the 659 calves included in the study, 593 had been weighed at both 4 and 60 days of age. Gain was computed by

subtracting the 4-day weight from the 60-day weight. Four-day weight and birth weight are considered synonymous in this study. The sex by breed by season by ration table had a possible 200 cells of which 135 contained one or more observations of 8-week gain. The symbolism used in analysis of these data follows:

μ = effect common to all calves

T_1 = males

T_2 = females

B_1 = Ayrshire

B_2 = Brown Swiss

B_3 = Guernsey

B_4 = Holstein

B_5 = Jersey

S_1 = Winter

S_2 = Spring

S_3 = Summer

S_4 = Fall

R_1 = antibiotic added

R_2 = liberal milk plus hay and grain

R_3 = limited milk plus hay and grain

R_4 = milk only

R_5 = filled milk containing unhydrogenated vegetable oil

The above symbols actually should have been designated

$\hat{w}$, $\hat{T}_1$, $\hat{T}_2$, etc., but for simplicity the hat symbol was eliminated. Any of the above symbols used from this point forward are understood to be estimates of $w - \overline{T} - \overline{B} - \overline{S} - \overline{R}$, $T_1 - \overline{T}$, $T_2 - \overline{T}$, $B_1 - \overline{B}$, ..., $B_5 - \overline{B}$, $S_1 - \overline{S}$, ..., $S_4 - \overline{S}$, $R_1 - \overline{R}$, ..., $R_4 - \overline{R}$, and $R_5 - \overline{R}$, respectively.

In order to evaluate properly the cell to cell variation, constants were fitted by the process described in the preceding section. The normal equations are in Table 7 and the constants and differences between the constants are in Table 8.

From ration, breed, sex, and season differences observed for the first 8 weeks, it can be seen that male calves grew more rapidly than female calves; there were large differences among rations with the antibiotic groups producing most weight gain and the unhydrogenated vegetable oil group the least; season differences were small; and the Ayrshires, Brown Swiss, and Holstein breeds gained more weight than the Jersey and Guernsey breeds. In view of the supposition that birth weight may affect rate of gain, the birth weight constants were derived and are presented in Table 9.

These differences tended to indicate that a part of the breed and sex differences in 8-week gain might be related to breed and sex differences in birth weight. In order to check this point an analysis of covariance was computed and the results are presented in Table 10.

Table 7. Matrix notation of the normal equations for birth weight and 8-week g

593	298	295	186	164	108	135	46	62	42	395	48	102	207	118	117	49
298	298		95	86	44	73	27	28	19	196	28	42	104	55	68	29
295		295	91	78	64	62	19	34	23	199	20	60	103	63	49	20
186	95	91	186				22	25	16	107	16	32	47	33	48	26
164	86	78		164			12	11	9	121	11	26	73	12	36	17
108	44	64			108		3	11	7	77	10	21	34	36	16	1
135	73	62				135	9	15	10	90	11	23	53	37	17	5
46	27	19	22	12	3	9	46					6	20	1	10	9
62	28	34	25	11	11	15		62				6	24	14	14	4
42	19	23	16	9	7	10			42			11	19	4	6	2
395	196	199	107	121	77	90				395		67	119	98	82	29
48	28	20	16	11	10	11					48	12	25	1	5	5
102	42	60	32	26	21	23	6	6	11	67	12	102				
207	104	103	47	73	34	53	20	24	19	119	25		207			
118	55	63	33	12	36	37	1	14	4	98	1			118		
117	68	49	48	36	16	17	10	14	6	82	5				117	
49	29	20	26	17	1	5	9	4	2	29	5					49

rmal equations for birth weight and 8-week gain values

											Gain		Birth weight
62	42	395	48	102	207	118	117	49	w		23628		50092
28	19	196	28	42	104	55	68	29	T_1		12392		26159
34	23	199	20	60	103	63	49	20	T_2		11236		23933
25	16	107	16	32	47	33	48	26	S_1		6729		15713
11	9	121	11	26	73	12	36	17	S_2		6928		14084
11	7	77	10	21	34	36	16	1	S_3		4417		8949
15	10	90	11	23	53	37	17	5	S_4		5554		11346
				6	20	1	10	9	B_1		1829		3806
62				6	24	14	14	4	B_2		2498		5658
	42			11	19	4	6	2	B_3	=	1354	or	2949
		395		67	119	98	82	29	B_4		16220		34863
			48	12	25	1	5	5	B_5		1727		2816
6	11	67	12	102					R_1		5523		8246
24	19	119	25		207				R_2		9770		17317
14	4	98	1			118			R_3		4470		10258
14	6	82	5				117		R_4		3026		10232
4	2	29	5					49	R_5		839		4039

Table 8. Eight-week gain constants derived by solving normal equations, and differences between sexes, seasons, breeds, and rations

	T_1	T_2	S_1	S_2	S_3	S_4
Constants[a]	3.08±.66[b]	-3.08±.66	-.44±1.07	2.00±1.11	-.46±1.30	-1.10±1.19
Differences between constants						
T_2	6.16±1.31					
S_2			2.44±1.69			
S_3			.02±1.96	2.46±2.02		
S_4			.66±1.82	3.10±1.87	.64±2.06	

	B_1	B_2	B_3	B_4	B_5
Constants	5.30±2.05	4.61±1.82	-8.64±2.11	4.29±1.15	-5.55±2.02
Differences between constants					
B_2	.69±3.11				
B_3	13.94±3.40	13.25±3.17			
B_4	1.01±2.52	.32±2.18	12.93±2.60		
B_5	10.85±3.28	10.16±3.08	3.09±3.35	9.84±2.47	

	R_1	R_2	R_3	R_4	R_5
Constants	19.27±1.43	11.33±1.14	1.07±1.41	-11.36±1.35	-19.81±1.93
Differences between constants					

	B_1	B_2	B_3	B_4	B_5
Constants	5.30±2.05	4.61±1.82	-8.64±2.11	4.29±1.15	-5.55±2.02
Differences between constants					
B_2	.69±3.11				
B_3	13.94±3.40	13.25±3.17			
B_4	1.01±2.52	.32±2.18	12.93±2.60		
B_5	10.85±3.28	10.16±3.08	3.09±3.35	9.84±2.47	

	R_1	R_2	R_3	R_4	R_5
Constants	19.27±1.43	11.33±1.14	1.07±1.41	-11.36±1.35	-19.81±1.93
Differences between constants					
R_2	7.94±1.93				
R_3	18.20±2.19	10.26±1.92			
R_4	31.13±2.18	23.19±1.87	12.93±2.13		
R_5	39.08±2.81	31.14±2.56	20.88±2.82	7.95±2.71	

[a]Constant w = 33.65.
[b]Standard errors.

Table 9. Birth weight constants derived by solving normal equations, and differences between sexes, seasons, breeds, and rations

	T_1	T_2	S_1	S_2	S_3	S_4
Constants[a]	3.61±.49[b]	-3.61±.49	.82±.80	.71±.84	-.88±.97	-.65±.89
Differences between constants						
T_2	7.22±.98					
S_2			.09±1.27			
S_3			1.70±1.47	1.59±1.52		
S_4			1.47±1.37	1.36±1.40	.23±1.54	

	B_1	B_2	B_3	B_4	B_5
Constants	4.88±1.54	12.39±1.37	-8.24±1.59	10.05±.86	-18.89±1.51
Differences between constants					
B_2	7.51±2.33				
B_3	13.12±2.55	20.63±2.38			
B_4	5.17±1.89	2.34±1.63	18.29±1.95		
B_5	23.77±2.46	31.28±2.31	10.65±2.51	28.94±1.85	

	R_1	R_2	R_3	R_4	R_5
Constants	-.78±1.07	1.31±.85	.28±1.06	1.26±1.01	-2.06±1.45
Differences between constants					

Constants	4.88±1.54	12.39±1.37	-8.24±1.59	10.05±.86	-18.89±1.51
Differences between constants					
B_2	7.51±2.33				
B_3	13.12±2.55	20.63±2.38			
B_4	5.17±1.89	2.34±1.63	18.29±1.95		
B_5	23.77±2.46	31.28±2.31	10.65±2.51	28.94±1.85	

	R_1	R_2	R_3	R_4	R_5
Constants	-.78±1.07	1.31±.85	.28±1.06	1.26±1.01	-2.06±1.45
Differences between constants					
R_2	2.09±1.45				
R_3	1.06±1.64	1.03±1.44			
R_4	2.04±1.63	.05±1.40	.98±1.60		
R_5	1.28±2.10	3.37±1.92	2.34±2.12	3.32±2.04	

[a]Constant μ = 77.60.
[b]Standard error.

Table 10. Results of analyses of variance and covariance of 8-week gain and birth weight values

Source of variance	d.f.	M.S. birth weight	M.S. 8-week gain	M.S. 8-week gain adjusted for birth weight
Season	3	103	281	245
Sex	1	7992**	5409**	2607**
Ration	4	158	21886**	21803**
Breed	4	12570**	2410**	814**
Interactions	122	139	288	303
Within cells	458[a]	140	249	243

[a]457 for adjusted 8-week gain mean square.

**F significant at the 1% level of probability.

At this point, it would seem that:

(1) The ration groups differ in level of growth response during the first 8 weeks of life.

(2) Males gain faster than females during the first 8 weeks. A part of this growth difference can be traced to difference in birth weight.

(3) The breeds differ in their rate of growth during the first 8 weeks. Again, part of this difference can be traced to difference in birth weight.

(4) Season of birth has no appreciable effect on rate

of gain from birth to 8 weeks of age.

(5) Birth weight has a low degree of relationship with 8-week gain as measured by within cell correlation ($r = .161 \pm .046$).

(6) There are true sex and breed effects independent of variation in birth weight.

A look at the data in graphic form tends to further clarify the above statements. Figure 1 clearly indicates the nature of the ration differences on an average daily gain or growth curve basis. The Holstein female group was selected as an example because it contained a large number of calves. The ration effect was relatively constant over all breed by sex classifications. A majority of the calves in the antibiotic group were on the limited milk regime (see Table 2), so their growth should be compared with the limited milk group in estimating growth response due to feeding either aureomycin or terramycin.

Figure 2 does not clearly illustrate the breed and sex differences found by least squares analysis but does seem to point to the fact that the growth curves are all of the same general nature. Since the curves were based on arithmetic averages, distribution of rations in the various breed and sex classes could be partially responsible for making the growth curves so similar. The breed and sex effects on growth are, however, very evident in the bar graph presented

Figure 1. Growth curves (birth to 8 weeks of age) of Holstein females on the five rations

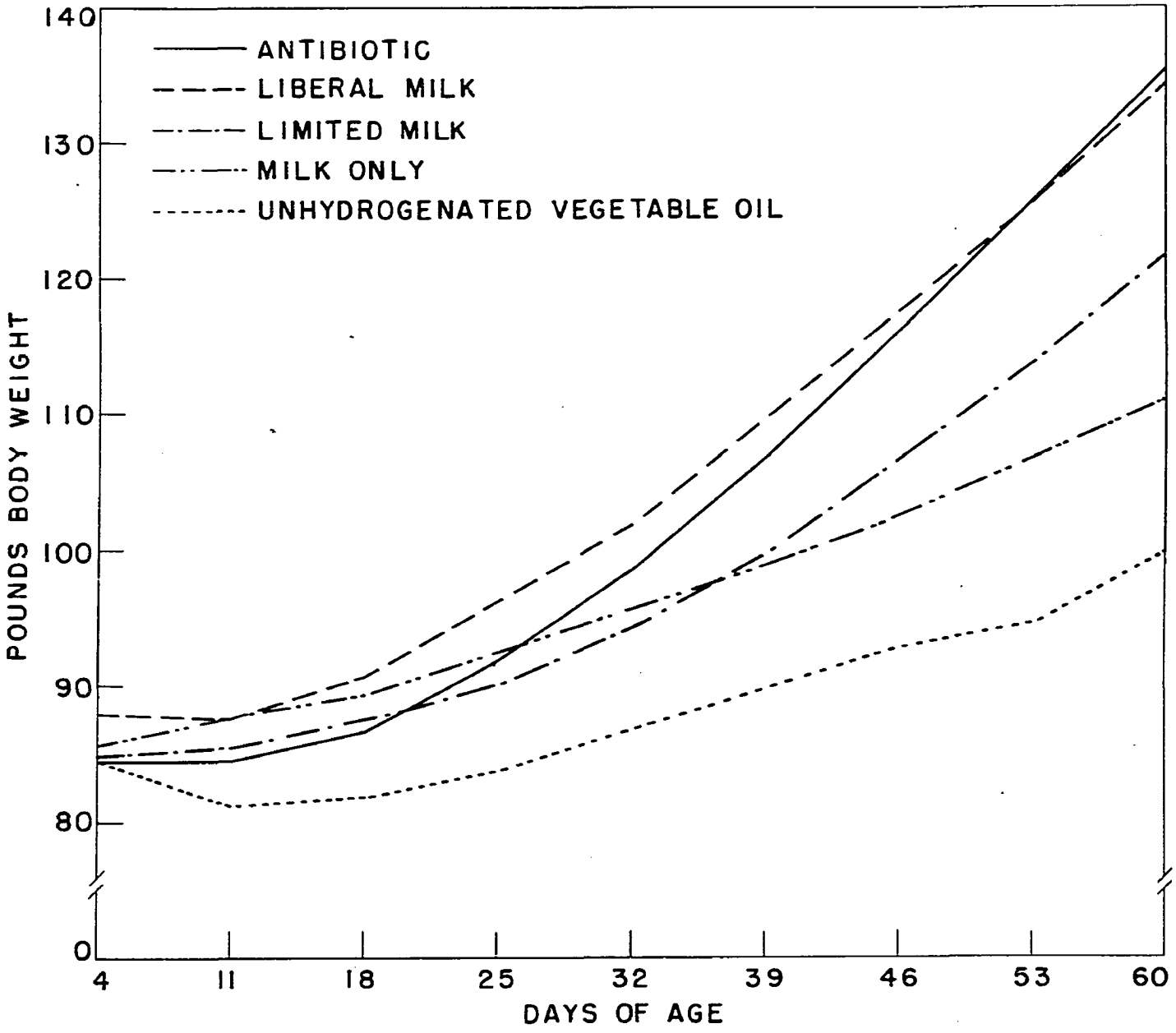
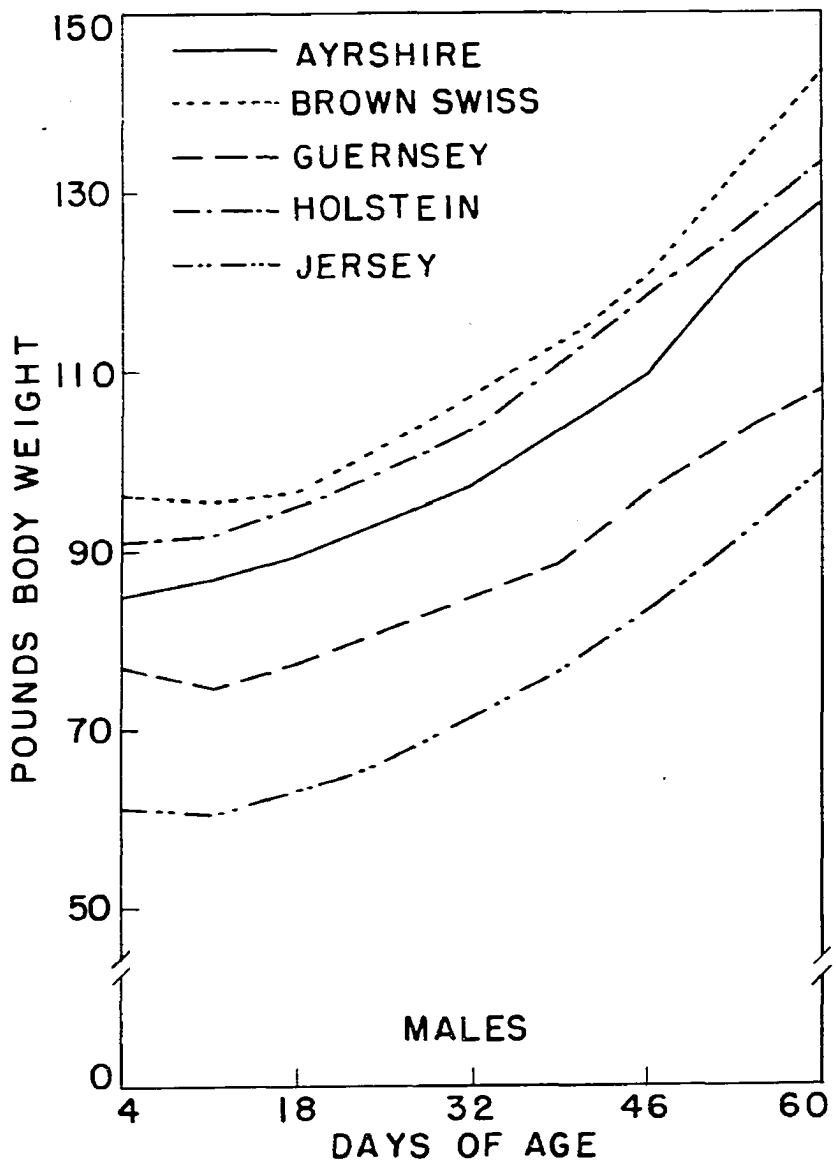
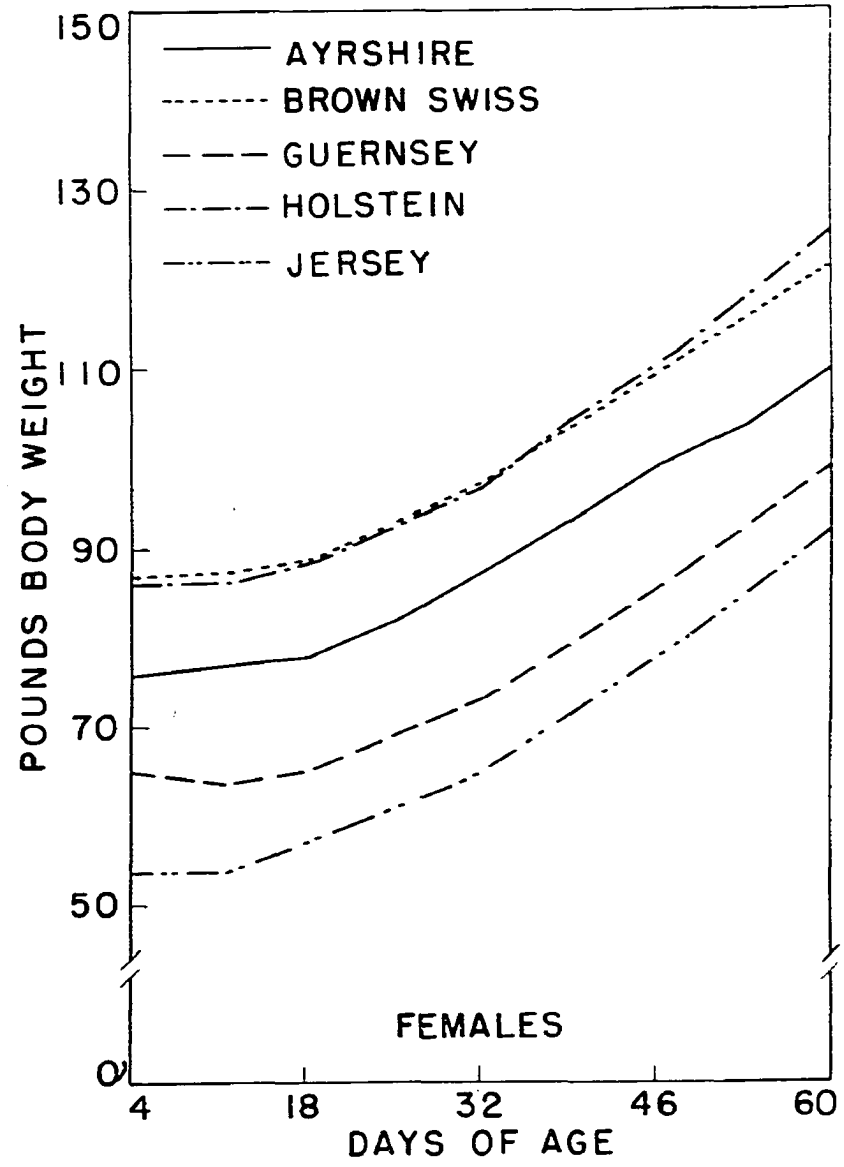

ANTIBIOTIC
LIBERAL MILK
LIMITED MILK
MILK ONLY
UNHYDROGENATED VEGETABLE OIL
POUNDS BODY WEIGHT
140
130
120
110
100
90
80
0
4
11
18
25
32
39
46
53
60
DAYS OF AGE

Figure 2. Arithmetic average body weights (birth to 8 weeks of age) of males and females of the Ayrshire, Brown Swiss, Guernsey, Holstein, and Jersey breeds


150
130
110
90
70
50
0
POUNDS BODY WEIGHT
AYRSHIRE
BROWN SWISS
GUERNSEY
HOLSTEIN
JERSEY
MALES
4
18
32
46
60
DAYS OF AGE


150
130
110
90
70
50
0
POUNDS BODY WEIGHT
AYRSHIRE
BROWN SWISS
GUERNSEY
HOLSTEIN
JERSEY
FEMALES
4
18
32
46
60
DAYS OF AGE

in Figure 3.

Brody (15) observed that the growth process takes the form of an exponential curve and devised a formula for determining the growth rate of an animal relative to the size of the animal at a given time. Thus, in place of computing daily gain, $\frac{W_2 - W_1}{t_2 - t_1}$, Brody would use the measure $\frac{dW/dt}{W}$ where W_2 = final weight, W_1 = initial weight, $t_2 - t_1$ = time interval and where dW/dt = differential of weight with regard to time and W = weight at any given time.

If $\frac{dW/dt}{W} = k$ where k = instantaneous relative growth rate, it follows that $dW/dt = kW$ and that $dW/W = kdt$. Integrating between W_1 and W_2 and between t_1 and t_2:

$$\int_{W_1}^{W_2} \frac{dW}{W} = k\int_{t_1}^{t_2} dt ,$$

$$\ln W_2 - \ln W_1 = k(t_2 - t_1) ,$$

$$k = \frac{\ln W_2 - \ln W_1}{t_2 - t_1} ,$$

and $\frac{\ln W_2 - \ln W_1}{t_2 - t_1} \times 100$ = instantaneous per cent relative growth rate.

The above formula for instantaneous per cent relative growth rate was used to compute values for Holstein calves in the various ration groups. A comparison of these values with average daily gain values is in Table 11. The meaning

Figure 3. Histogram of birth weights and 8-week gain values of the males and females of the Ayrshire, Brown Swiss, Guernsey, Holstein, and Jersey breeds

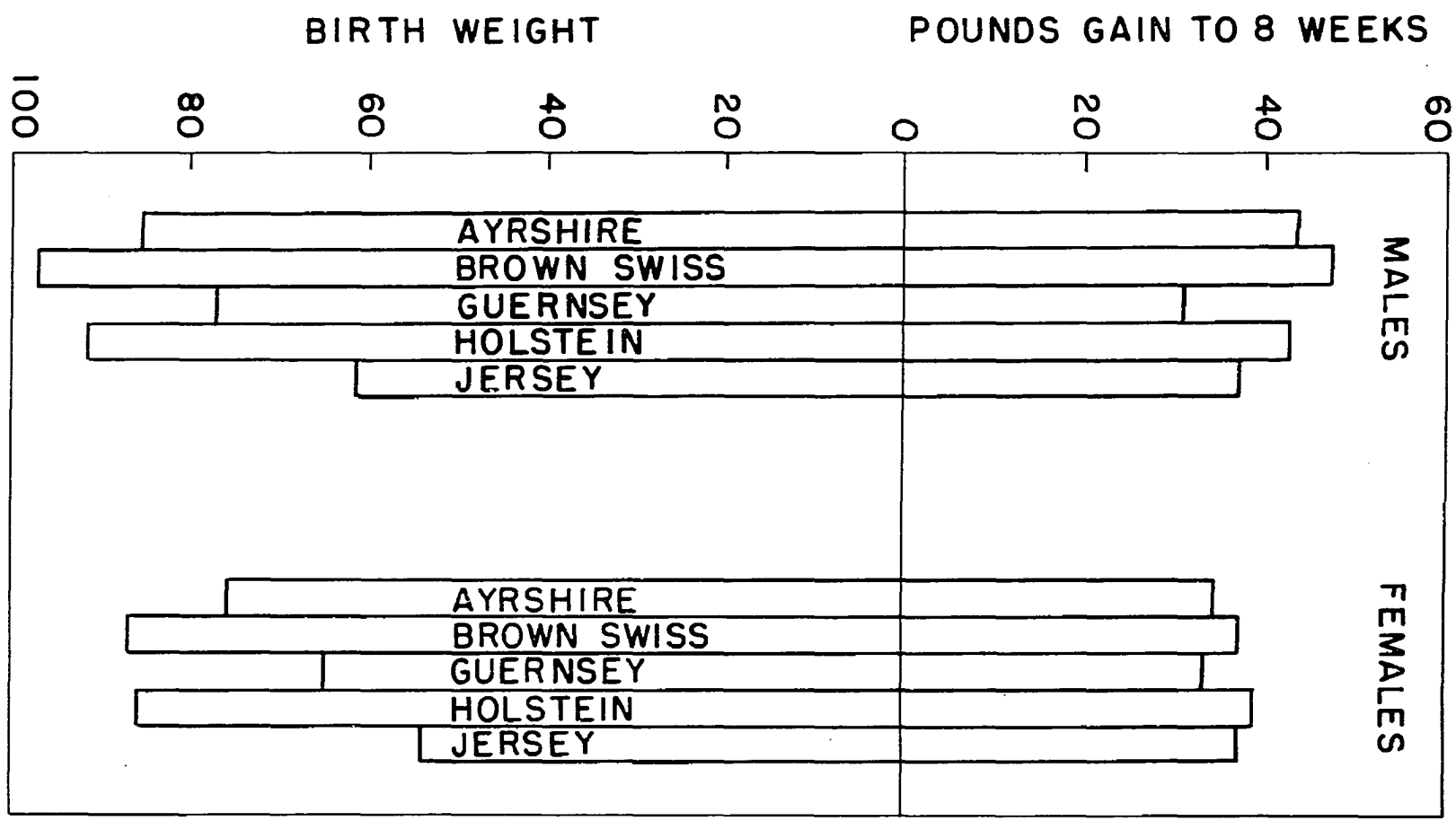

BIRTH WEIGHT
POUNDS GAIN TO 8 WEEKS
100
80
60
40
20
0
20
40
60
AYRSHIRE
BROWN SWISS
GUERNSEY
HOLSTEIN
JERSEY
MALES
AYRSHIRE
BROWN SWISS
GUERNSEY
HOLSTEIN
JERSEY
FEMALES

Table 11. Per cent relative growth rate and daily gain of Holstein calves from birth to 4 weeks and from 4 weeks to 8 weeks of age

Ration	Sex	Birth to 4 weeks		4 weeks to 8 weeks	
		Relative rate	Daily gain	Relative rate	Daily gain
Anti-biotic	Male	.73	.73	1.06	1.36
	Female	.55	.50	1.13	1.31
Liberal milk	Male	.55	.55	1.04	1.30
	Female	.51	.49	1.00	1.17
Limited milk	Male	.39	.38	.99	1.10
	Female	.37	.33	.91	.98
Milk only	Male	.44	.43	.61	.70
	Female	.38	.34	.54	.55
Unhydro-genated vegetable oil	Male	.07	.06	.56	.56
	Female	.08	.07	.50	.46

of instantaneous per cent relative growth rate is that an animal will gain that per cent of its weight during a given unit of time. The day was used as a unit of time in this study. For example, a calf weighing 100 pounds on the 12th day of its life and having an instantaneous per cent relative growth rate of .78 per cent per day would be expected to gain .78 pounds during the 12th day of its life.

It would appear that from birth to 8 weeks of age daily rate of gain and per cent relative growth rate are very

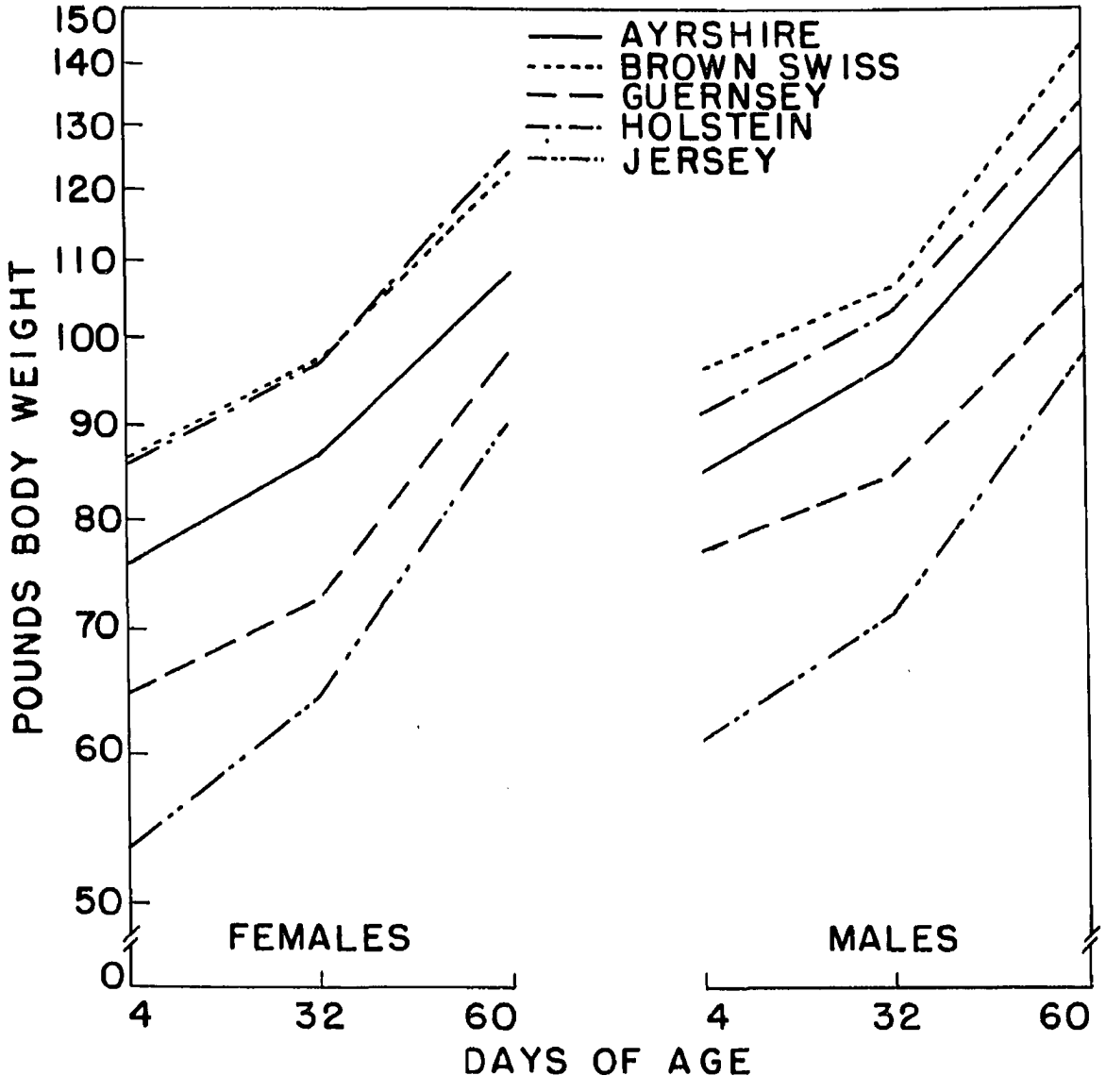
closely associated. Since the values presented in Table 11 were for the Holstein breed and Holstein calves weigh approximately 100 pounds during a large part of the first 8 weeks of life, the relative rates of gain were automatically similar to the daily rates of gain. Table 11 also indicates that the ration effect may be greater in the first 4 weeks than in the second 4 weeks of life.

Figure 4 serves to illustrate the breed and sex differences in relative growth rate. The most striking observation is that Jerseys seem to grow much more rapidly than the other four breeds in the period from birth to 8 weeks of age. Figure 3 and Table 8 substantiate this observation.

2. Growth from 4 days to 6 months of age

Six-month weights were available on very few animals of breeds other than Holsteins, so the study of growth from birth to six months was limited to the one breed. Only 19 Holsteins having 6-month weights and birth weights did not have 8-week weights; therefore, it seemed advisable to exclude those calves from the study and obtain an estimate of whether the ration effects were largely confined to the first 8 weeks of life or if they carried over into the following 4 months of life. Symbols and methods used in the

Figure 4. Rate of growth relative to size (birth to 8 weeks of age) of males and females of the Ayrshire, Brown Swiss, Guernsey, Holstein, and Jersey breeds; body weight plotted on a logarithmic scale; slopes of the plotted lines measure relative growth rate


AYRSHIRE
BROWN SWISS
GUERNSEY
HOLSTEIN
JERSEY
POUNDS BODY WEIGHT
150
140
130
120
110
100
90
80
70
60
50
0
FEMALES
MALES
4
32
60
4
32
60
DAYS OF AGE

study of 8-week gain values were used in this analysis. Normal equations used in obtaining the constants are in Table 12.

Six-month gain constants and differences enumerated in Table 13 show that there were differences among the ration groups and between the sexes. The season of birth again had little or no effect on growth. Table 14 reveals that there was a sex difference from birth to 6 months of age and that there was sex differentiation from 8 weeks to 6 months of age independent of that from birth to 8 weeks of age. A further, and possibly more important observation, was that the major part of the ration differences were exerted in the first 8 weeks of life. Though the differences between rations were greater at 6 months of age than at 8 weeks of age, those differences were directly correlated with the differences at 8 weeks of age. Table 15 compares the ration constants for 8-week and 6-month gain values. It can be seen that the difference between any two rations is generally greater at 6 months than at 8 weeks of age. In general, the calves were under approximately the same feeding and management conditions from 8 or 12 weeks to 6 months of age.

In order to check the magnitude of difference between rations at 8 weeks and 6 months of age, the average daily gain values for each sex and ration group from 8 weeks to

Table 12. Matrix notation of the normal equations for birth weight, 8-week gain, and 6-month gain values

													6-month gain		8-week gain
296	123	173	75	95	60	66	37	94	79	61	25	μ	68648		12244
123	123		38	41	17	27	17	33	30	30	13	T_1	30560		5443
173		173	37	54	43	39	20	61	49	31	12	T_2	38088		6801
75	38	37	75					18	17	27	13	S_1	16892		2704
95	41	54		95			13	39	9	24	10	S_2	22199		4210
60	17	43			60		12	13	30	5		S_3	13440		2364
66	27	39				66	12	24	23	5	2	S_4	16117	or	2966
37	17	20		13	12	12	37					R_1	9502		2026
94	33	61	18	39	13	24		94				R_2	22966		4802
79	30	49	17	9	30	23			79			R_3	17967		3036
61	30	31	27	24	5	5				61		R_4	13545		1881
25	13	12	13	10		2					25	R_5	4668		499

$=$

or

ion of the normal equations for birth weight, 8-week
month gain values

							6-month gain		8-week gain		Birth weight
66	37	94	79	61	25	w	68648		12244		26261
27	17	33	30	30	13	T_1	30560		5443		11366
39	20	61	49	31	12	T_2	38088		6801		14895
		18	17	27	13	S_1	16892		2704		6883
	13	39	9	24	10	S_2	22199		4210		8516
	12	13	30	5		S_3	13440		2364		5110
66	12	24	23	5	2	S_4	16117	or	2966	or	5752
12	37					R_1	9502		2026		3266
24		94				R_2	22966		4802		8469
23			79			R_3	17967		3036		6929
5				61		R_4	13545		1881		5466
2					25	R_5	4668		499		2131

Table 13. Six-month gain constants derived by solving normal equations and differences between sexes, seasons, and rations

	T_1	T_2	S_1	S_2	S_3	S_4
Constants[a]	15.15±2.24[b]	-15.15±2.24	1.30±4.08	1.40±3.65	-9.35±4.34	6.64±3.79
Differences between constants						
T_2	30.30±4.49					
S_2			.10±5.96			
S_3			10.65±7.11	10.75±6.65		
S_4			5.34±6.75	5.24±6.21	15.99±6.75	

	R_1	R_2	R_3	R_4	R_5
Constants	25.59±5.58	18.76±3.92	3.44±4.33	-7.30±4.58	-44.49±6.56
Differences between constants					
R_2	6.83±7.41				
R_3	22.15±7.57	15.32±5.97			
R_4	32.89±8.26	26.06±6.34	10.74±6.85		
R_5	70.08±10.21	63.25±8.64	47.93±9.08	37.19±8.88	

[a]Constant μ = 228.84.
[b]Standard error.

Table 14. Results of analyses of variance and covariance of birth weight, 8-week gain, and 6-month gain values

Source of variance	d.f.	M.S. 6-month gain	M.S. 6-month gain adjusted for birth weight	M.S. 6-month gain adjusted for 8-week gain	M.S. 6-month gain adjusted for 8-week gain & birth weight
Sex	1	63601**	42448**	27519**	20963**
Season	3	2664	2476	1451	1662
Ration	4	23771**	19402**	1672	1398
Interactions	27	1209	1166	971	879
Within cells	260[a]	1393	1304	871	845

[a]259 degrees of freedom for 6-month gain mean square adjusted for either birth weight or 8-week gain; 258 degrees of freedom for 6-month gain mean square adjusted for 8-week gain and birth weight.

**F significant at the 1% level of probability.

Table 15. A comparison of ration constants for 8-week gain and 6-month gain

Ration	Constants for 8-week gain from analysis of 8-week gain data	Constants for 8-week gain from analysis of 6-month gain data	Constants for 6-month gain
1	19.27	16.32	29.59
2	11.33	12.29	18.76
3	1.07	1.26	3.44
4	-11.86	-9.20	-7.30
5	-19.81	-20.66	-44.49

6 months of age were computed and are listed in Table 16. The per cent relative growth rate values were computed for the same period and are also listed in Table 16. It seems that all ration groups grew at about the same rate relative to their attained size but at considerably different rates measured in pounds per day per animal from age 8 weeks to age 6 months. Within cell sums of squares and crossproducts computed for Table 14 were used to compute correlations among the three characteristics. Correlations were: birth weight and 8-week gain .195±.060, birth weight and 6-month gain .260±.058, 8-week gain and 6-month gain .615±.039. The latter correlation was partially automatic inasmuch as 8-week gain was a part of 6-month gain.

Table 16. Daily rate of gain and per cent relative growth rate values for Holstein calves from 8 weeks to 6 months of age

Sex	Measure	Ration				
		1	2	3	4	5
Males	Relative rate	.74	.76	.78	.79	.79
	Daily gain	1.78	1.80	1.72	1.66	1.43
Females	Relative rate	.75	.71	.74	.81	.77
	Daily gain	1.65	1.50	1.46	1.53	1.29

3. Growth from 4 days to 1 year of age

Calves having both 4-day and 1-year weights were essentially the same as those used in analysis of 6-month gain except that many of the males had been eliminated. The analysis of 1-year gain values was limited to the Holstein breed. The normal equations are in Table 17 and the constants derived from the equations and differences between the constants are in Table 18. These constants reveal that the sex difference at 1 year of age was even larger than at 6 months of age. The rations were still in the same order and season of birth effects were significant for the first time.

Table 17. Matrix notation of the normal equations for birth weight and 1-year gain values

													Gain		Birth weight
214	44	170	56	64	42	52	20	84	49	42	19	μ	107216		18950
44	44		19	8	7	10	3	14	10	11	6	T_1	23721		4061
170		170	37	56	35	42	17	70	39	31	13	T_2	83495		14889
56	19	37	56					15	13	19	9	S_1	27246		5126
64	8	56		64			6	29	5	15	9	S_2	32973		5697
42	7	35			42		5	14	18	5		S_3	= 20911	or	3527
52	10	42				52	9	26	13	3	1	S_4	26186		4600
20	3	17		6	5	9	20					R_1	10820		1806
84	14	70	15	29	14	26		84				R_2	42719		7514
49	10	39	13	5	18	13			49			R_3	24246		4276
42	11	31	19	15	5	3				42		R_4	21003		3696
19	6	13	9	9		1					19	R_5	8428		1658

Table 18. One-year gain constants derived by solving normal equations and differences between sexes, seasons, and rations

	T_1	T_2	S_1	S_2	S_3	S_4
Constants[a]	29.85±5.65[b]	-29.85±5.65	-10.63±8.23	21.87±7.68	-6.35±8.79	-4.89±8.16
Differences between constants						
T_2	59.70±11.31					
S_2			32.50±12.47			
S_3			4.28±14.18	28.22±13.75		
S_4			5.74±13.62	26.76±12.76	1.46±13.78	

	R_1	R_2	R_3	R_4	R_5
Constants	46.49±12.96	12.78±7.69	4.05±9.32	.22±9.69	-63.11±13.24
Differences between constants					
R_2	33.71±16.42				
R_3	42.44±17.71	8.73±12.13			
R_4	46.27±18.71	12.56±12.88	3.83±14.43		
R_5	109.60±22.03	75.89±17.21	67.16±18.67	63.33±18.13	

[a]Constant μ = 512.63.
[b]Standard error.

The analyses of variance and covariance in Table 19 show that all effects were significant, including the pooled interaction term. Experiment effects were ignored in the original classification, but were recognized to

Table 19. Results of analyses of variance and covariance of 1-year gain and birth weight

Source of variance	d.f.	M.S. 1-year gain	M.S. 1-year gain adjusted for birth weight
Sex	1	118325**	88077**
Season	3	12155*	13529*
Ration	4	28646**	22305**
Interactions	23	9477**	8615**
Within cells	182	4258	3846

*F significant at the 5% level of probability.
**F significant at the 1% level of probability.

exist and to be highly confounded with ration effects (see Table 4). The deletion of calves could have unbalanced the cells with regard to experiments, thus allowing experiment effects to create the impression of interactions among sex, season of birth, and ration. In order to test whether or not the above was true, a set of normal equations including

experiment effects were solved. The pooled interaction remaining after fitting sex, season, ration, and experiment constants was nonsignificant; but the ration constants were extremely unrealistic due to the high degree of confounding between ration and experiment classification. The ration constants derived when experiment effects were included in the model were: $R_1 = 156.51$, $R_2 = 232.57$, $R_3 = 62.14$, $R_4 = -298.95$, and $R_5 = -147.67$. It is clearly ridiculous to suppose that calves given a liberal milk ration plus hay and concentrate the first 8 weeks of life should gain 531 pounds more from birth to 1 year of age than calves given milk only for the first 8 weeks of life. Since these constants could not be used to describe differences between rations, the first fit of constants was used to describe ration differences while the second fit was used to explain why the interactions were large in the first. Differences between sexes and among seasons were very similar in both sets of constants, so the first set was used to describe these differences also.

Correction of gain for birth weight made no difference in the degree of significance of the various effects though birth weight and 1-year gain had a within cell coefficient of correlation of $.319 \pm .067$. The magnitude of ration constants was greater than in the analysis of 6-month gain data. Relative rates of gain and daily rates of gain for Holstein females from 6 months to 1 year of age are listed

in Table 20.

It would appear that the animals on the poorer rations in early life have a tendency to start catching up with animals on the better rations between 6 months and 1 year of age. These values (Table 20), being based on arithmetic average weights, cannot be taken as other than a rather rough estimate of the true situation.

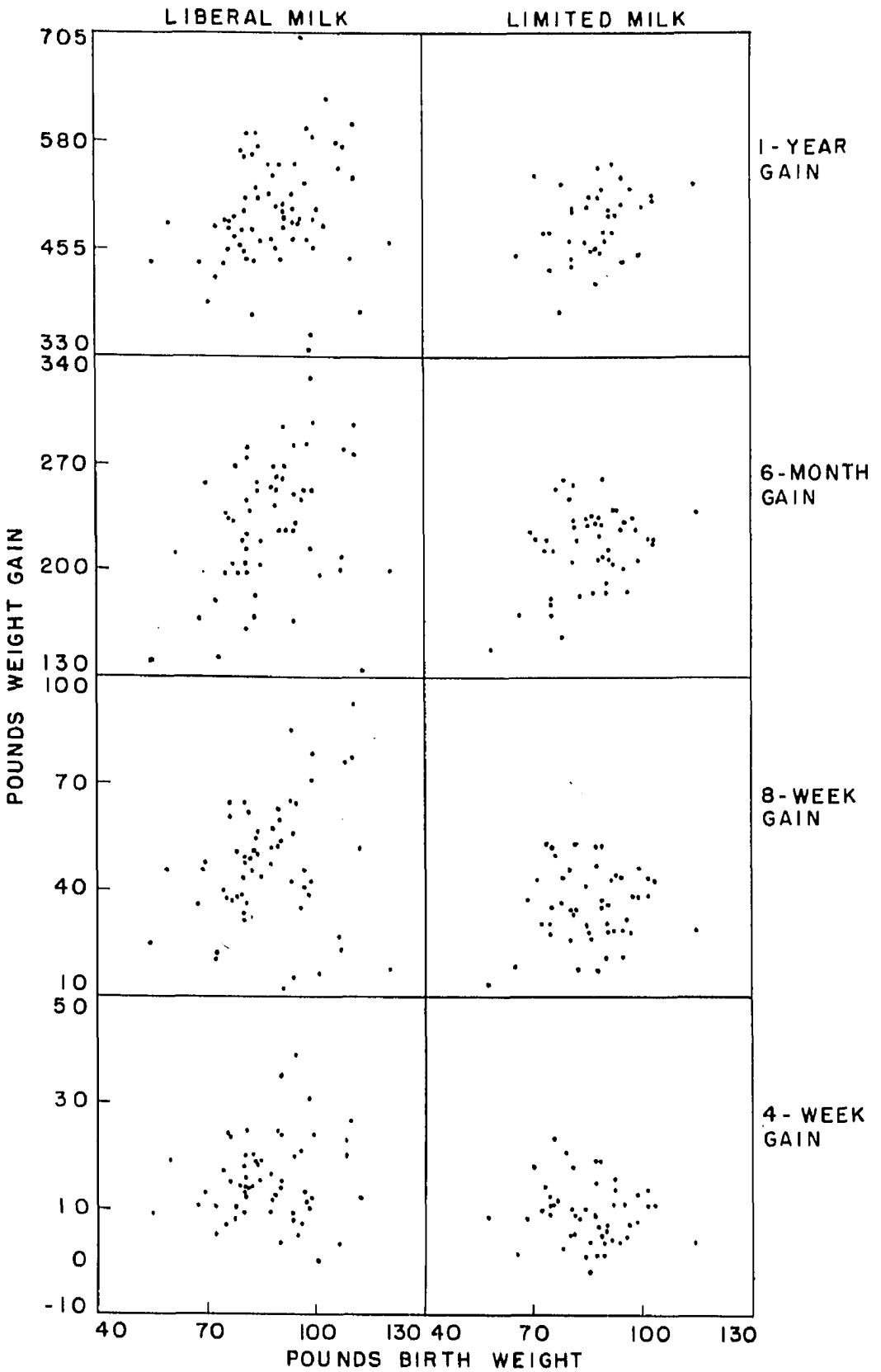
Table 20. Per cent relative growth rate and pounds gain per day between 6 months and 1 year of age for Holstein females

	Ration				
	1	2	3	4	5
Relative gain	.33	.33	.35	.37	.42
Daily gain	1.50	1.46	1.48	1.55	1.60

C. Correlation of Birth Weight with Weight Gains

From the correlations derived in preceding sections, it appeared evident that the relationship between birth weight and gains for various periods of the animal's life did not remain constant. Figure 5 shows the relationship of birth weight to 4-week, 8-week, 6-month and 1-year gain values. Holstein females of the liberal and limited milk

Figure 5. Relationship between birth weight and gains in Holstein females fed liberal milk and limited milk diets from birth to 8 weeks of age


LIBERAL MILK
LIMITED MILK
1-YEAR GAIN
6-MONTH GAIN
8-WEEK GAIN
4-WEEK GAIN
POUNDS WEIGHT GAIN
705
580
455
330
340
270
200
130
100
70
40
10
50
30
10
0
-10
40
70
100
130
POUNDS BIRTH WEIGHT

rations were chosen because there were greater numbers in those groups. The distributions of the above groups were representative of the other groups. It appeared that gain was not greatly affected by birth weight. Relationship between gain and birth weight tended to increase as the period from birth to age of measurement increased.

Holstein calves were then divided into groups according to birth weight and average gains and per cent relative growth rates were computed. The only class having a reasonable number of animals in all birth weight classes was the Holstein females on the liberal milk ration. Numbers ranged from four under 70 pounds to 20 in the 80 to 89 pound class. The above values are listed in Table 21.

It was quite noticeable that the heavier calves at birth seemed to be somewhat heavier at the four ages, but the lighter calves seemed to have a tendency to grow faster relative to their weight. Both of the above tendencies were more marked at 6 months and 1 year of age than at either 4 weeks or 8 weeks of age.

The nature of the changing relationship between birth weight and gains is more definitely defined by the correlations in Table 22.

All of the correlations listed in Table 22 were computed from pooled sums of squares and crossproducts within cells of a breed by sex by season by ration classification.

Table 21. Daily gain and per cent relative rate of growth from birth to 4 weeks, 8 weeks, 6 months, and 1 year of age for Holstein females fed a liberal milk diet from birth to 8 weeks of age

Birth weight class	No. calves	Ave. birth weight	Ave. 4-week gain	Ave. 8-week gain	Ave. 6-month gain	Ave. 1-year gain
Under 70	4	62.2	12.8	38.6	259	498
70 to 79	10	75.4	13.4	40.7	286	538
80 to 89	20	82.4	16.4	47.6	309	589
90 to 99	17	94.0	17.3	50.6	349	595
100 and over	8	108.9	10.3	47.7	332	628

Birth weight class	Relative rate to 4 weeks	Relative rate to 8 weeks	Relative rate to 6 months	Relative rate to 1 year
Under 70	.67	.86	.92	.61
70 to 79	.58	.77	.88	.58
80 to 89	.65	.81	.87	.58
90 to 99	.60	.77	.87	.55
100 and over	.60	.79	.83	.55

Table 22. Correlations between birth weight and gains for varying periods from birth

Data	d.f.	Gain to age: 2 wks.	4 wks.	6 wks.	8 wks.	12 wks.	16 wks.	6 mos.	1 year
8-week gain analysis	457				.161**				
6-month gain analysis	259				.195**			.260**	
1-year gain analysis	181								.319**
Holstein calves all gains to 8 weeks	349	-.100	.057	.133*	.164**				
Holstein calves all gains to 16 weeks	149	-.051	.131	.244**	.297**	.382**	.272**		
Holstein calves all gains except 12 and 16 weeks	161	-.159*	.001	.107	.188*			.316**	.327**
Analysis of gains related to age at calving and milk production	95				.166			.356**	.291**

*Significant at the 5% level of probability.
**Significant at the 1% level of probability.

The largest correlation found was that between birth weight and 12-week gain. Correlation of birth weight with gains to 8 weeks of age or less were less than .30 and the correlation values of birth weight with gains to 12 weeks or older ages were between .30 and .40 in most cases. Thus, birth weight accounts for less than 16 per cent of the total variability in body weight gains. The negative correlation between 2-week gain and birth weight indicates at least a tendency for the heavier calves to grow slower immediately after birth.

D. Correlation of Weight Gains with Age at Calving and Production

Of the calves included in the study of factors affecting growth, 113 Holstein females had all of the following measures: birth weight, 8-week gain, 6-month gain, 1-year gain, age at first calving, and first lactation milk production. These data were used to compute correlations among the above characters. Age at first calving was recorded to the nearest tenth part of a year. Production records were based on two times per day milking and were converted to a 305-day, mature equivalent, 3.5 per cent fat basis. Correction factors for conversion to mature equivalent were taken from D.H.I.A. Letter 29:7 (68). Record length conversion factors

(1) as interpolated by McGilliard (46) were used to standardize record length. Correction to 3.5 per cent fat was selected because that value was near the Holstein herd average in the Iowa State College herd. Correction factor for conversion to standard fat was .43 x milk + 16 x fat which was derived by McGilliard (46) from work by Gaines (31).

Since season had little effect on gains and the animals in any given ration group were fairly equally divided among the seasons, a simple among and within ration analysis of variance was computed to test significance of among ration variance for each trait listed above. This analysis of variance is in Table 23. The outstanding inconsistency noted between the above analysis and the previously presented analysis is the failure of ration groups to differ in 1-year gain values. Ration differences in 1-year gain approached significance at the 5 per cent level of significance. The analyses of growth presented in previous sections describe ration differences more accurately than the one in Table 23 due to the greater numbers involved in those analyses. The ration groups did differ in age of first calving but there was no specific tendency for age at calving to be associated with growth rate. The ration averages in Table 24 show that, in these data, early age at calving was by no means perfectly related to rapid growth. The

Table 23. Analysis of variance of birth weight, gain, age of first calving, and production of Holstein females

Source of variance	d.f.	M.S. birth weight	M.S. 8-week gain	M.S. 6-month gain	M.S. 1-year gain	M.S. age at calving	M.S. production
Rations	4	124	4750**	12128**	7447	.168**	1084
Error	108	157	213	1236	3702	.034	501

**F significant at the 1% level of probability.

Table 24. Ration averages of birth weight, gain, age at first calving, and production of Holstein females

Ration	Birth weight	8-week gain	6-month gain	1-year gain	Age at calving	Production[a]
1	92.4	72.2	272.8	540.4	1.98	134
2	87.6	47.3	232.4	500.4	2.23	124
3	83.9	39.5	217.6	480.7	2.08	135
4	85.2	26.2	209.3	488.9	2.27	123
5	83.3	15.8	171.8	457.5	2.22	111

[a]Production measured to nearest 100 pounds of 3.5% F.C.M., M.E., 305-day record.

ration groups did differ in production during the first lactation, but that difference did not attain statistical significance.

A more exact measure of the relationships among the above listed characteristics was found by computing the within ration correlations which are listed in Table 25. Birth weight had a lower degree of correlation with 8-week gain than with either 6-month or 1-year gain. Birth weight was positively correlated with milk production and negatively correlated with age at calving with both correlations being significant at the 5 per cent level. The three measures of gain were negatively associated with age at

Table 25. Correlations between birth weight, 8-week gain, 6-month gain, 1-year gain, age at first calving, and production based on 107 degrees of freedom within ration

	8-week gain	6-month gain	1-year gain	Age at calving	Production
Birth weight	.127	.324**	.260**	-.188*	.217*
8-week gain		.573**	.321**	-.056	.072
6-month gain			.539**	-.059	.257**
1-year gain				-.056	.223*
Age at calving					.014

*Significant at the 5% level of significance.
**Significant at the 1% level of significance.

calving but none of the coefficients of correlation were significant. These small negative correlations of birth weight and gain with age at calving could be largely attributed to the managerial practice of breeding heifers according to size. Eight-week gain was not significantly correlated with production, but both 6-month gain and 1-year gain were significantly and positively correlated with production in the first lactation.

As a check, the same correlations were also computed within ration by season classification. In general, the above correlations (see Table 26) were larger than those

Table 26. Correlations between birth weight, 8-week gain, 6-month gain, 1-year gain, age at first calving, and production based on 95 degrees of freedom within ration and season

	8-week gain	6-month gain	1-year gain	Age at calving	Production
Birth weight	.166	.356**	.291**	-.205*	.276**
8-week gain		.578**	.337**	-.104	.088
6-month gain			.559**	-.058	.300**
1-year gain				-.067	.301**
Age at calving					.044

computed within ration. The significant coefficients were the same in both cases.

Significance of the correlation coefficients was tested by the t test. According to Fisher (27), the standard deviation of a correlation coefficient is approximated by $\frac{1 - r^2}{\sqrt{d.f.}}$ for a reasonably small correlation based on a large number of degrees of freedom. Fisher (27) also proved $r\sqrt{\frac{1 - r^2}{d.f.}}$ to be distributed as t and Snedecor (61) has listed necessary correlation values for significance at the 1 per cent and 5 per cent levels.

Production was not correlated with age at calving.

This can be explained by the fact that the production records were age corrected. The large correlation between the various measures of gain can be partially accounted for by the fact that 8-week gain is a part of both 6-month and 1-year gains and 6-month gain is a part of 1-year gain.

V. DISCUSSION

The data used in this study were of such a nature as to make certain calculations more reliable than others due to the fact that the volume of data involved in specific calculations varied. Experiments from which data were taken for this study were, for the most part, conducted from 4 days to 8 weeks of age. All Holsteins and Guernseys remaining in the herd to 6 months and 1 year of age were weighed at those ages, while other animals were weighed at 6 months and/or 1 year of age only if the experiment to which they were assigned extended to that age. Some experiments extended to 12 weeks of age and some calves were weighed at intervals between 12 weeks and 6 months of age.

The amount of information on gains for various periods from birth varied greatly. Analysis of gains for periods up to 8 weeks from birth was based on 350 or more Holsteins and 40 or more animals in each of the other breeds while analysis of gains to 1 year of age was based on about 200 Holsteins. Beyond 8 weeks of age, the breeds other than Holsteins were represented by so few animals it was not considered worthwhile to include them. Thus, information about growth response of the breeds was limited to the early age period and information concerning the effects of season of birth, sex, and ration was more reliable in the

first 8 weeks due to the larger number of animals included in the analysis of growth in this period.

Rathore (57) and Morrison (47) each stated that his study was hampered by the reduced numbers available at older ages. Of nearly 200 male Holsteins having 8-week gain values in the present study, only 44 had 1-year gain values.

Birth weight was affected by sex of the calf and by breed, as evidenced by Tables 9 and 10. Other workers (22, 23, 28, 56, 66) previously found one or both to affect birth weight. In this study, factors affecting birth weight were of less interest than the effect of birth weight on gain.

Both breed and sex differences or effects were significant ($P \leq .01$) in the analysis of 8-week gain (Table 12). Computation of the sums of squares due to the above factors after adjustment for birth weight differences revealed that both effects remained significant ($P \leq .01$), but the reduced F values indicated that the effects of breed and sex independent of birth weight were smaller.

Components of variance were not computed in this study, but it can be seen in Table 10 that σ^2 is estimated as 249 and 243, respectively, in unadjusted and adjusted analyses. The mean squares for sex are each estimates of $\sigma^2 + k_0\sigma^2_T$, sex being a fixed variable. Subtracting the within cell

mean square from each sex mean square, $k_0\sigma^2_T$ is estimated as 5160 and 2464 by the unadjusted and adjusted analyses, respectively. A similar argument shows the adjusted and unadjusted analyses to estimate $k_0\sigma^2_B$ (breed variance) as 571 and 2161, respectively. The reduced value of these components of variance indicates that birth weight did influence the differences in gain attributable to breed and sex.

From the above arguments, it can be seen that animals being assigned to experimental treatments should be assigned in some way which would prevent confounding breed and sex effects with treatment effects. A randomized block design wherein all animals in a block are of the same breed and sex probably best fits this situation. If, however, the person planning the experiment is willing to accept a less exact estimate of treatment effects, an unbalanced design could be used and a part of the breed and sex effects removed by covariance analysis with birth weight being the independent variable and gain the dependent variable.

Breed differences were not estimated at 6 months and 1 year of age. Sex difference became greater as age increased as can be seen from the fact that the difference of gains between males and females progressed from 6.16 pounds at 8 weeks to 30.30 pounds at 6 months to 59.70 pounds at 1 year of age. Males were 7.22 pounds heavier

at birth than were females. Adjustment of 6-month gain values for 8-week gain and birth weight failed to remove significance of the sex effect. Thus, it seems that the male calves continually gain faster than the female calves and, though the growth curves are similar in shape, they definitely are not similar in daily rate of gain.

No analysis of variance of relative rate of gain values was computed, but an examination of Table 11 reveals that the males tended to gain faster relative to their size than the females during the initial 8 weeks of life. The sex difference in relative rate of gain was not so obvious from 8 weeks to 6 months of age (see Table 16). The sex difference would appear to be a "snowballing effect". Some inherent characteristic causes a difference of about 13 pounds body weight to be manifest at 8 weeks of age. Even if growth from 8 weeks forward proceeds at the same rate of growth relative to accumulated weight, the compound interest nature of growth causes the male to gain more pounds per day due to the already accumulated difference. The sex difference in absolute weight constantly increases as the animals become older. Of course, it must be remembered that the male is characteristically heavier than the female at maturity.

From the above, relative rate of growth can be suggested as a possible means of measuring growth relatively

free of sex effect. It is quite clear, however, that daily rate of gain for males and females differs at all ages studied.

Season of birth effects were non-significant at 8 weeks and at 6 months of age as evidenced by Tables 10, 12, 15, and 16. The empirical classification of season of birth used in this analysis is such that calves born near the end of a given season would be nearer calves born early in the following season than calves born early in the same season. The results found can be interpreted as meaning that the average conditions of the four seasons are equally conducive to growth. The results cannot be interpreted, for example, to mean that extreme heat or extreme cold would not cause an animal to slow its growth rate for the duration of the stress period. At 1 year of age there was a difference in gain due to season of birth. Why should that difference show up in 1-year gain when it has not been present previously? The most plausible explanation is that the animals were placed on pasture or in an open shed at about 6 months of age and were more subject to the elements and the variation in quality and quantity of feed from season to season. Constants for season (Table 18) show that spring calves are heavier than calves born in the other seasons. Management practices regarding rate of feeding in March and April and the availability of pasture

in late April and in May could contribute to the heavier weights of these animals. Spring calves are also likely to be fed dry feed (including considerable concentrates) almost constantly from birth to about 1 year of age. An increased growth to 1 year of age would be the logical result of grain feeding.

A possibility not to be ignored is the fact that deletion of calves could have seriously unbalanced the season groups with regard to the frequency of the experiment and ration classifications. It was previously explained that fitting of constants including an experiment classification reduced the interactions to a non-significant level. The experiments included would have to be considered as random selections from an infinity of possible experiments. If experiment effect is random and the pooled interaction term includes some variability due to this random effect, the interaction term becomes a more plausible error term than the within cell variance. Testing season effect against the interaction term of either analysis resulted in nonsignificance. Thus, the significance of season effect was subject to doubt.

Since there is some question as to why the season effect became significant in the 1-year analysis and, in fact, some question as to whether the season effect was truly significant, it cannot be considered as being too

important. In order to be assured that the season effect is not causing treatment differences in studies extending to 1 year of age, it would be highly advisable to compare the treatments on animals as nearly contemporary as possible. The season effect is of no great importance if the experiment is to be concluded at an age of 6 months or less.

It was found that ration affects growth to all ages considered in this study. This cannot be considered as surprising in view of the findings of experiments from which data were taken for this study.

From 6 months to 1 year, both the daily rates and the relative rates of gain tended to indicate that the previously underfed animals were gaining on the better fed animals. In view of the general shape of the growth curve, this is not surprising. The point of most rapid gain is somewhere in this range. The well fed animals would tend to reach the point of inflection earlier and then start to decline in relative rate of gain while the previously underfed animals would tend to remain in the self-accelerating phase of growth to a later age and would have a greater portion of their period of most rapid gain in this period.

From this study, the indications are that a rapid gaining ration group tends to maintain its weight advantage to 1 year of age. The workers (21, 35, 58) who have most carefully studied the effects of ration on growth

have continued the ration for longer periods than 12 weeks from birth, so their findings are not strictly applicable to this case. Further study of this problem is necessary to determine the specific age at which equality of weight is reached. Workers cited above found no difference in mature weight of animals fed limited and liberal rations to approximately 2 years of age when the animals were fed liberally thereafter.

Birth weight was found to affect rate of gain to a small degree. Smaller calves seemed to gain less weight per day but more weight per unit accumulated weight than larger calves (Table 21). The correlation between birth weight and gain tended to increase up to 12 weeks of age, but was less than .40 at all ages. The literature on this specific topic is rather sparse, but Espe et al. (26) reported greater variability at early ages than at older ages and Rathore (57) found the pattern of breed differences in size to more closely resemble breed differences in birth weight at older ages than in the first few months of life. Blackmore (9) studied heritability of body weight at 6 months, 1 year, and 2 years of age and observed an increased heritability of body weight as age increased. All of the above facts tend to indicate that growth may be highly subject to environmental variation the first few months after birth. The correlation is not large enough at any point

to warrant grouping calves according to birth weight prior to assignment to experimental treatments.

It could be hypothesized that birth weight and mature size are more closely associated genetically than birth weight and early growth. In such a situation, changing from the protected intra-uterine environment to the more vulnerable extra-uterine environment leaves the calf subject to many environmental changes. In this period of adjustment, the inherent size of the animal and the birth weight have little effect on growth as compared to the many environmental stresses and strains. Following the adjustment period, the inherent size factor present in the animal exerts itself to cause the animal to grow at a rate sufficient to reach the inherited mature size.

From this hypothesis, it would seem that the most opportune time to test the value of certain calf rations is early in the calf's life. How much of the early life should be used is another question. There obviously is some age at which environmental influences exert their effects in such a way as to represent a maximum percentage of the total variability. Whether that age is 2, 4, 6, 8, or 12 weeks or some other age should be answered in some future study. It could easily be true, for example, that a test of significance of gains to 4 weeks of age would be more sensitive to ration differences than a test of

significance of gains to any other age.

The importance of rapid growth in a dairy heifer has been the subject of previous work. Eckles (21) and Eckles and Swett (25) concluded that the rate of growth and consequent age at maturity could be influenced by rate of feeding. It was concluded in those studies that the more economical managerial practice would be to grow heifers at a rapid rate in order to breed them earlier. They found no difference between underfed and normally fed heifers in ability to produce milk. More recently, Reid (58) and Hansson et al. (34) reached the same conclusions regarding rate of growth and age at maturity.

Less drastic treatments were studied in the present investigation, but the findings were the same. Neither milk production nor age at calving was significantly affected by rate of growth to 8 weeks of age. Growth to 6 months and 1 year of age was correlated with milk production, but Gjelstad (32), Bailey and Broster (4), and Blackmore (9) all reported low correlations between body weight and milk production.

Birth weight was correlated with milk production ($r = .217$) to a higher degree than was reported by either Blackmore (9) or Straus (62). Both reported a genetic relationship between birth weight and production.

The effects of ration on age at calving and on

production were too slight to be of importance in determining what rations or managerial practices should be followed in raising heifers. In view of the above findings and the work by Hansson et al. (35) indicating that slow growth is related to longevity, the importance of rate of growth can be reduced to two considerations: (1) Is it more economical to grow heifers fast and breed early or slow down growth and get longer life? and (2) Is growth an index of the desirability of a managerial and/or feeding regime?

The first question cannot be answered here due to data limitations. The second question is subject to some conjecture, but rate of growth is generally accepted as a measure of health and vigor. Strong, thrifty, healthy calves are the object of most dairy herdsmen, so growth rate should be a satisfactory measure of the adequacy of feeding and managerial programs.

Growth standards have been tabulated by Ragsdale (53), Morrison (47), Espe et al. (26), Campbell and Flux (19) and Eckles (24). A comparison of these values with average and adjusted values for animals included in this study is in Table 27. From the adjusted averages, it can be seen that Rations 1 and 2 compare favorably with most of the standards. Ration 3 is very near the arithmetic average at the three ages studied, thus, the arithmetic average of growth data included in this study could well serve as

Table 27. Growth standard values for Holstein heifers at birth, 2 months, 6 months, and 1 year of age; values derived from the present study based on 170 or more animals

Standard	Birth	2 months	6 months	1 year
Campbell and Flux (19)		160[a]	390	575
Eckles (24)	90	157	349	558
Espe et al. (26)	89	132	358	662
Morrison (47)	91	150	365	653
Ragsdale (53)	90	148	355	632
Present study:[b]				
(1) Arithmetic average	86	125	307	579
(2) Adjusted to:				
(a) w	86	121	301	573
(b) R_1	86	140	326	619
(c) R_2	86	131	319	586
(d) R_3	86	122	304	577
(e) R_4	86	109	293	573
(f) R_5	86	101	256	510

[a]Read from a graph.

[b]Averages presented in Tables 24 and 27 are not comparable because only a portion of the data was used for Table 24.

a standard for limited milk diets. Averages adjusted to Ration 2 would probably more nearly approach the management practiced by the average and better-than-average farmer.

Adjusted averages presented in Table 27 were computed by utilizing previously derived constants to eliminate ration differences. For example: if there were N animals of which N_1 received R_1, N_2 received R_2, ..., and N_5 received R_5. The average adjusted to R_1 would be

$$\frac{\sum_{\ell} \left[N_{\ell}(R_1 - R_{\ell}) + \sum (\text{gains of calves receiving } R_{\ell}) \right]}{N} + \text{average}$$

birth weight.

The great variability of these data plus the variability reported by Ragsdale and Regan (55) would lead one to question what is "normal". The value of the average curve is certainly not as great as some of the early literature would lead one to believe.

Further investigations suggested by this study include the following:

(1) An accurate and detailed study of the value of relative rates of growth in interpreting experimental results.

(2) An accurate investigation of the age at which calves retarded in growth by early ration gain enough weight to become as large as their contemporaries fed more liberal and satisfactory rations early in life.

(3) Determination of the age at which ration variance is a maximum percentage of total variance and, consequently, would allow the most information to be gained concerning ration effects on growth.

(4) A study of the value of linear body measurements in evaluating the adequacy of ration and/or management practices.

VI. SUMMARY AND CONCLUSIONS

Available body weight data to 1 year of age on 659 dairy calves which had been on nutrition experiments were used to study the effects of breed, sex, season of birth, ration, and birth weight on growth of dairy calves. The associations of birth weight and body weight gain with age at calving and milk production of Holstein heifers were studied also.

Analysis of variance and covariance and estimation of differences between the sexes, rations, breeds, and seasons were accomplished by fitting constants. The model assumed for the analysis was:

$$Y_{ijk\ell m} = \mu + T_i + B_j + S_k + R_\ell + e_{ijk\ell m}$$

where $Y_{ijk\ell m}$ represents a weight gain observation in the indicated cell of the four way classification, μ is a constant common to all calves, T_i is a sex effect, B_j is a breed effect, S_k is a season of birth effect, R_ℓ is a ration effect and $e_{ijk\ell m}$ is a deviation peculiar to the m^{th} calf in the $ijk\ell^{th}$ cell of the classification.

Males were found to gain significantly more than females to 8 weeks, 6 months, and 1 year of age. The sex difference increased with age and was partially independent of the birth weight difference. The sex difference in gain to 6 months was significant after adjustment for 8-week gain.

Correction for birth weight reduced the magnitude of the sex effects.

The breeds were found to differ in 8-week gain both before and after adjustment for birth weight. Adjustment for birth weight reduced the magnitude of breed variation. Insufficient data were available to compute breed differences to 6 months and 1 year of age.

Season of birth effects on growth were found to be non-significant to 8 weeks and 6 months of age but were found to be significant to 1 year of age. Possible explanations of this phenomenon are discussed.

Ration effects were highly significant at all ages studied. Antibiotic (aureomycin or terramycin), liberal milk (over 300 pounds), limited milk (under 300 pounds), milk only (no hay or grain to 8 weeks) and rations containing unhydrogenated vegetable oil were ranked in that order according to ability to produce body weight gain. Ration effects to 6 months of age were non-significant when 6-month gain was corrected for 8-week gain. Ration differences tended to persist to 1 year of age, though there seemed to be a slight tendency for calves from the poorer rations to begin to "catch up" between 6 months and 1 year of age.

Correlations of birth weight with body weight gain tended to increase as the age to which gain was computed increased. Correlations of birth weight with gain to 2,

4, 6, and 8 weeks of age were less than .30 while correlations of birth weight with 12-week, 16-week, 6-month, and 1-year gains were, in most cases, between .30 and .40. Thus, birth weight within breed, sex, ration, and season would account for less than 16 per cent of the total variability in body weight gain.

Correlations of birth weight and gain values with age at calving were small but negative and could be explained as probably being due to the practice of breeding according to size. Correlations of gain values with production were positive but too small to indicate that first lactation production could be greatly improved by growing heifers rapidly.

Relative rates of gain were used to help explain ration, breed, and sex effects and it was found that relative rates and daily rates of gain were sometimes different. From this study, it could be concluded that:

(1) Males and females differ in rate of gain.

(2) The breeds differ in rate of gain.

(3) Season of birth does not seriously affect body weight gain.

(4) Ration during the first 8 weeks of life affects gain for that period.

(5) Ration differences tend to persist as late as 1 year of age.

(6) Birth weight differences affect gain but the coefficient of correlation is small ($r < .40$).

(7) Correlation of birth weight with gain from birth to a given age increases as the age to which gain is computed becomes greater to 12 weeks of age.

(8) Correlations of birth weight and gain with production and age at calving exist but are so small that the latter factors are not important in determining how to feed and manage calves the first 8 to 12 weeks.

(9) Reference growth curves should be carefully selected and should be used with some discretion in interpreting experimental results.

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